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Results from a 2-year (nominal) deployment of a moored array along 152°E from 28°N to 41°N are presented, with emphasis on similarities and differences between settings (approximately year-to-year). Ten moorings and 38 instruments were involved, from the fall of 1980 to 1982. Current-temperature meters spanned the water column from 500- to 4000-m depths, with occasional instruments in the vicinity of 300 m and near the bottom (~6000 m). Upper level features located in the center of the array near 35°–36°N were generally stable relative to the axis of the Kuroshio Extension, varying from deployment to deployment with meanders in this flow regime. Some properties of the abyssal (~4000 m) currents were comparatively more variable, with these changes not connected to meandering of the Kuroshio Extension in an obvious way. The vertical structure and frequency distributions of eddy kinetic energy were similar in shape and to some extent in amplitude from deployment to deployment, especially relative to meanders of the Kuroshio Extension, but translated in the opposite direction.

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Two-Year Moored Instrument Results Along 152°E

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1. INTRODUCTION

The first long-term moored array across a sizable section of the mid-latitude North Pacific [*Schmitz et al.*, 1982] was initially set in 1980 and recovered for the last time in 1982. Observations were made along 152°E from 28° to 41°N across the Kuroshio Extension in two deployments of 10 moorings for roughly a year each. This moored instrument data acquisition was accompanied by conductivity-temperature-depth (CTD) and expendable bathythermograph (XBT) observations. One of the more prominent results from the first deployment was a maximum abyssal eddy kinetic energy of about 50 $cm^2\ s^{-2}$, located near the upper level expression of the Kuroshio Extension, in contrast with analogous results from the Gulf Stream system of 100–150 $cm^2\ s^{-2}$ [*Schmitz et al.*, 1982]. Abyssal energy levels for the second setting were compared with the first deployment by *Schmitz* [1984*a*], and a general pattern of stability was found, with some variations. *Niiler et al.* [1985] observed a relatively stable baroclinic transport relative to the bottom from year to year, although the transports associated with their 4000-m mean flows are quite variable (see below and *Schmitz* [1987]). Other selected results from both deployments of this array and associated CTD/XBT data have been presented by *Koblinsky et al.* [1984] and *Schmitz* [1984*a*, *b*]; see also *Schmitz and Holland* [1986]. This note summarizes a variety of observations from both deployments, with emphasis on comparison between them.

2. THE DATA BASE

Thirty-eight current-temperature meters were moored for about 2 years (two deployment-retrieval cycles) along 152°E from 28° to 41°N (Figure 1). Ten moorings (Table 1) were involved, at a planned latitudinal spacing of 1.25° in the center of the array and 2° at the extremes. Each mooring had instruments at nominal or design depths of 500, 1200, and 4000 m, with four moorings also having instruments near 300-m depth as well as 200 m off the bottom (typically near 6000-m depth). The nomenclature "nominal or design depth" refers to vertical location in the absence of currents or errors in wire and other mooring component measurement. The upper level expression of the Kuroshio Extension was located near 35°–36°N while the array was in place, as inferred both from CTD sections taken during the cruises when the moorings were handled, XBT surveys [*Koblinsky et al.*, 1984] taken concurrently, and upper level mean flows based on the moored instrument data. Preliminary results from the first array setting have been described by *Schmitz et al.* [1982]. Similar methods and procedures were used for the second deployment [*Schmitz*, 1984*a*, *b*]. A data report is available [*Levy and Tarbell*, 1983]. Technical considerations are described in some detail by *Bradley* [1982]. Portions of the data from the North Atlantic along 55°W [*Schmitz*, 1978, 1980] referred to in the following were also described and compared with 152°E data by *Schmitz et al.* [1982]. The CTD data taken during cruises to service moorings have been summarized by *Williams and Niiler* [1981], *Niiler and Whitman* [1982], and *Niiler et al.* [1985].

Each mooring is assigned a number sequentially as deployed by the buoy group at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Instruments are then identified by adding a digit to the end of the mooring number, starting from the top of the mooring. For example, 7241 is the shallowest instrument on mooring 724. Mooring numbers (Table 1) for the first array setting were 695–704 and similarly 718–728 for the second deployment (where one mooring number was aborted owing to a problem during launch). Sites are numbered WP01 to WP10 from north to south (Table 1).

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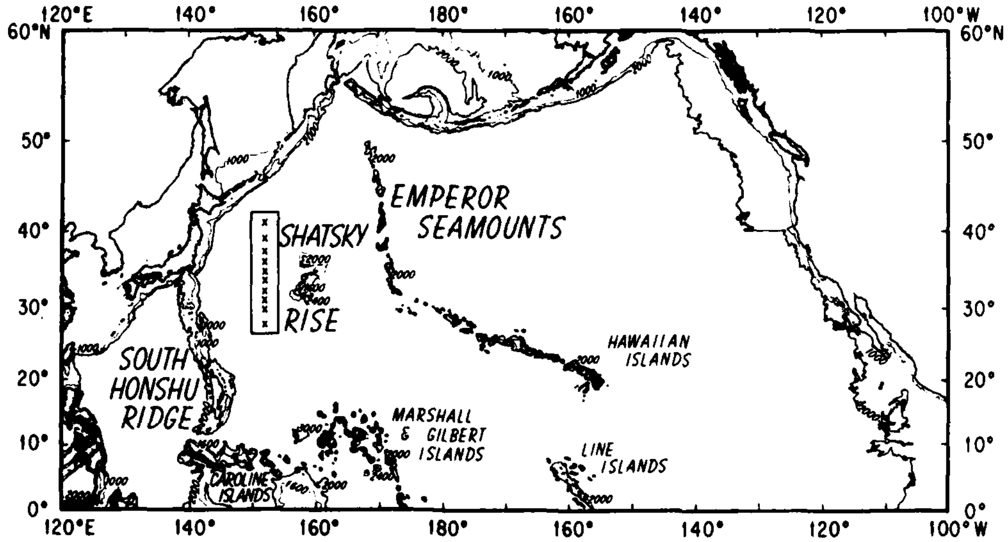

Fig. 1. Mooring locations along 152°E, denoted by crosses enclosed in a rectangular box. Depth contours in fathoms (1 fathom = 1.8 m) and feature names taken from *Chase et al.* [1977].

Instrument performance is summarized in Figure 2. All 10 instruments at 4000-m depth worked during the first setting; for the second, there were seven high-quality data records (including one somewhat shorter series). There were no locations where data were not obtained for at least one setting; one mooring (720) was lost during the second deployment cycle. The first deployment was set from north to south and recovered (and replaced) from south to north so that the record lengths (for instruments with no problems) vary from 298 to 326 days from moorings 704 to 695. The second deployment was recovered as deployed from south to north so that record lengths are more uniform, 370 to 373 days. The variation in mean deployment duration was controlled by typical constraints of ship schedules.

Magnetic tape cassettes were extracted from the current-temperature meters, decoded, and placed in computer-compatible form. Each record was taken through standard quality control procedures, low-passed as described by *Schmitz et al.* [1982] and subsampled once per day. Various time averages and Fourier transforms are then routinely computed. The zonal and meridional (x, y) means and variances are denoted by ($\bar{u}$, $\bar{v}$) and ($\overline{u'^2}$, $\overline{v'^2}$); the overbar signifies a time average, and a prime superscript indicates the deviation from an average. Eddy kinetic energy (per unit mass, hereafter understood) is $K_E = 0.5\,(\overline{u'^2} + \overline{v'^2})$. In this context then, "eddies" are not necessarily closed circulation cells or any spatially restricted fluctuation, but encompass the low-frequency variability about the temporal mean. This includes periods longer than 2 days, and shorter than those covered by the mean (twice the record length by definition).

In calculating eddy frequency distributions, the inverse of the low-pass filter initially used is applied (recoloring) at frequencies lower than 0.5 cpd, a matter of consequence primarily for the period range near a few days. The discrete Fourier transform procedure employed assigns energy to each of the basic frequency bands $(\alpha \pm 0.5)\tau^{-1}$, where τ is the record length and $\alpha = 1, \cdots, N-1$; N is one-half the number

TABLE 1. Instrument Locations and Depths

Mooring Location (Nominal)	Site	Instrument Number: Deployment 1	Instrument Number: Deployment 2	Nominal Depth, m
152°E, 41.00°N	WP01	6951	7281	300
		6952	7282	600
		6953	7283	1200
		6954	7284	4000
		6955	7285	5800
152°E, 39.00°N	WP02	6961	7271	600
		6962	7272	1200
		6963	7273	4000
152°E, 37.50°N	WP03	6971	7261	600
		6972	7262	1200
		6973	7263	4000
152°E, 36.25°N	WP04	6981	7251	600
		6982	7252	1200
		6983	7253	4000
152°E, 35.00°N	WP05	6991	7241	300
		6992	7242	600
		6993	7243	1200
		6994	7244	4000
		6995	7245	5800
152°E, 33.75°N	WP06	7001	7221	600
		7002	7222	1200
		7003	7223	4000
152°E, 32.50°N	WP07	7011	7211	300
		7012	7212	600
		7013	7213	1200
		7014	7214	4000
		7015	7215	5800
152°E, 31.25°N	WP08	7021	7201	600
		7022	7202	1200
		7023	7203	4000
152°E, 30.00°N	WP09	7031	7191	600
		7032	7192	1200
		7033	7193	4000
152°E, 28.00°N	WP10	7041	7181	300
		7042	7182	600
		7043	7183	1200
		7044	7184	4000
		7045	7185	5800

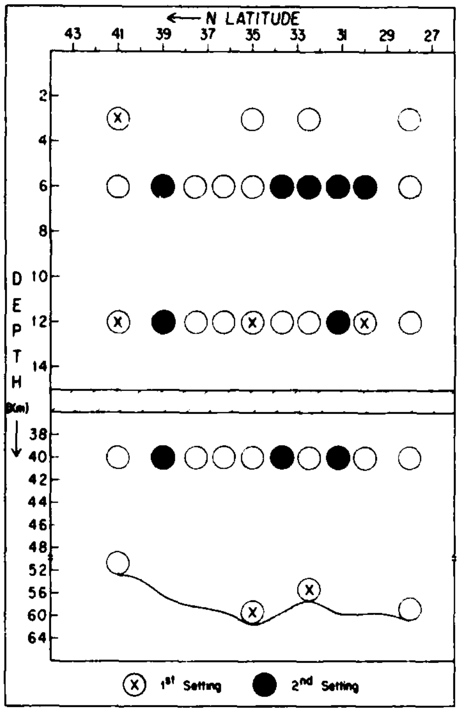

Fig. 2. A summary of data return. Each instrument is located on a section across the array by a circle: a cross inside indicates severe data loss for the first setting; a solid circle is used analogously for the second setting. Mooring 720 ($\sim 31°$N, second setting) was lost. There are no locations where data were lost for both settings.

of data days. The highest frequency ($\alpha = N$) is a cycle per 2 days and encompasses only half the bandwidth of the lower frequency estimates, as does the mean ($\alpha = 0$), which spans the frequency band from zero to $(2\tau)^{-1}$. The lowest frequency band above the mean contains contributions from the range of periods from $(\frac{2}{3} \rightarrow 2)\tau$, "centered" at τ.

A variety of techniques for describing spectral or frequency distributions may be used, depending on what one wants to emphasize. The summed energy in a few rather broad frequency bands or period ranges in the form of simple bar graphs is the basic time scale description used here: the notation $K_E(a, b)$ designates the eddy kinetic energy in the range of periods from a to b days (or the frequency band b^{-1} to a^{-1} cpd). The period ranges considered here are consistent with those employed, for example, by *Schmitz et al.* [1982] and *Imawaki and Takano* [1982]. They are K_E (20, 150), the temporal mesoscale; K_E (150, 2τ), where τ is record length, secular scale; K_E (2, 20), the "high" frequency band. K_E $(a, b)/\Sigma$, where Σ is the total K_E for all frequency bands plotted, is used when "spectral shape" is being intercompared.

3. MEAN VALUES

The basic time averages for the eddy field, for both settings, are contained in Figure 3 for each standard depth. Generally speaking, the variations from deployment to deployment (nominally, year to year) are not large, with a few exceptions.

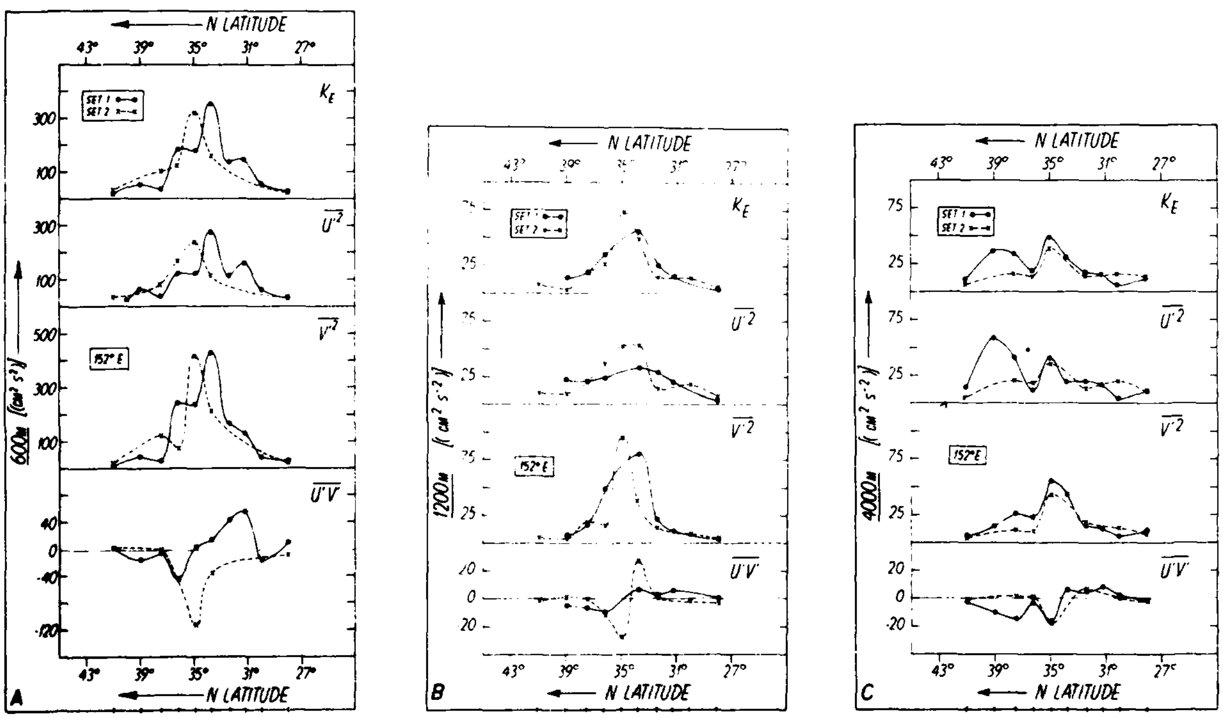

Fig. 3. Basic eddy field time averages (standard symbols, also defined in the text) for all standard depths for each setting: (*a*) 600 m, (*b*) 1200 m, and (*c*) 4000 m.

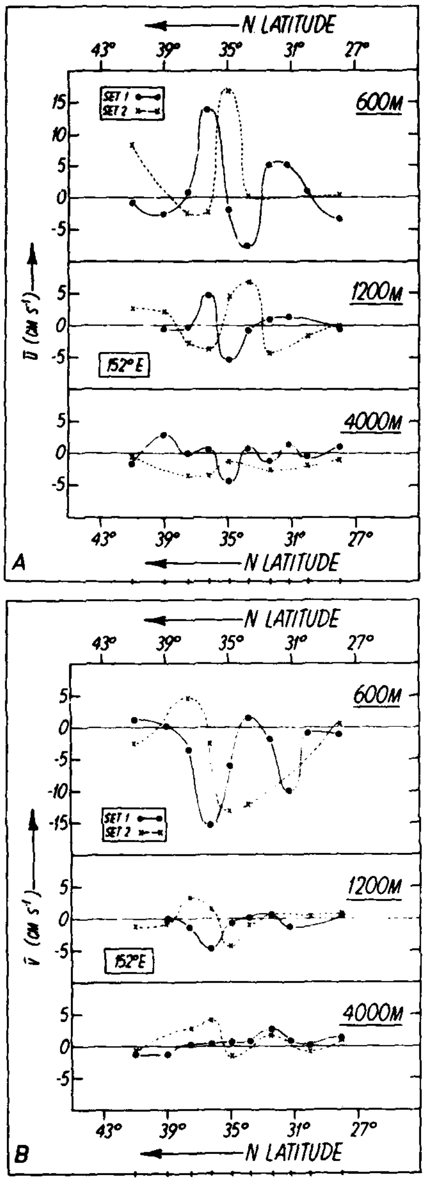

Fig. 4. Mean velocity components for all standard depths for each setting: (*a*) the zonal current component $\bar{u}$ and (*b*) the meridional current component $\bar{v}$.

There are latitudinal shifts of these distributions, by one site, at the upper levels (Figures 3*a* and 3*b*) associated with shifts in the location of the axis of the Kuroshio Extension. The most pronounced other differences between mooring deployments exist for $\overline{u'v'}$ at 600 m (Figure 3*a*), $\overline{u'v'}$ at 1200 m (Figure 3*b*), and $\overline{u'^2}$ (and therefore K_E) at 4000 m (Figure 3*c*). The differences in the $\overline{u'v'}$ distributions at 600 m, where there is a sign change in the southern sector of the array between deployments, could be associated with the loss of data (Figure 2) between 30° and 32.5°N at this depth for the second array setting. The difference between deployments for $\overline{u'v'}$ at 1200 m is a question more of amplitude than of shape of the distribution; 1200-m results are in general somewhat less energetic for the first array deployment. The differences in $\overline{u'^2}$ (and K_E) near 39°N for 4000-m depth are also associated with a missing data point.

The components of the mean or time-averaged flow for each deployment at the standard depths are contained in Figure 4. There are latitudinal shifts of these distributions at the upper levels, in this case meandering by definition. These shifts, latitudinally in the same direction for $\bar{u}$ and $\bar{v}$ by one or two mooring locations, are in the opposite direction to those for $\overline{u'^2}$ and $\overline{v'^2}$ (Figure 3) and therefore K_E. A year to year shift of the 4000-m K_E profile at 55°W in the North Atlantic along 55°W (Figure 5) also occurs in the opposite direction to latitudinal changes in Gulf Stream axis location [see also *Schmitz and McCartney*, 1982]. There is evidence in the upper levels of Figure 4 for eastward mean flows other than the Kuroshio Extension that are not reproduced from deployment to deployment. Upper level mean flows in Figure 4 are indicative of the Kuroshio Extension for mooring 698 (~36.25°N) and mooring 724 (~35°N) for the first and second array deployments, respectively [*Schmitz*, 1984*b*]. The CTD data acquired during mooring deployment cruises indicate that the axis of the Kuroshio Extension was in the vicinity of 36°N for the first setting and 35°N for the second.

Time-averaged current components $\bar{u}$ and $\bar{v}$ are somewhat less stable than the eddy field time averages and qualitatively most so for $\bar{u}$ at 4000-m depth. The 4000-m $\bar{u}$ distribution is of uniform sign for the second array setting, in contrast to low-amplitude (except for two moorings) pointwise variability about zero for the first setting of the array (there are also three fewer 4000-m data points for the second setting; see Figure 2). The section averaged zonal mean speeds [*Niiler et al.*, 1985, Figure 10] at 1200 m are quite stable in both sign and magnitude (small westward values) for the last 16 months of the 22-month (nominal) deployment whereas the 4000-m equivalent, although stable in sign, is much more variable in amplitude. The total baroclinic transport relative to the bottom is comparatively stable [*Niiler et al.*, 1985, Figure 5]. The variation between deployments in $\overline{u'^2}$ near the northern end of the array is associated with a variation in $\bar{u}$, of opposite sign for 600- and 1200-m depth versus 4000-m depth, again somewhat obscured by missing data points. Although it would be tempting to interpret these differences in terms of encroachment of the Oyashio system on the northern portion of the array during the second deployment, the picture is unclear.

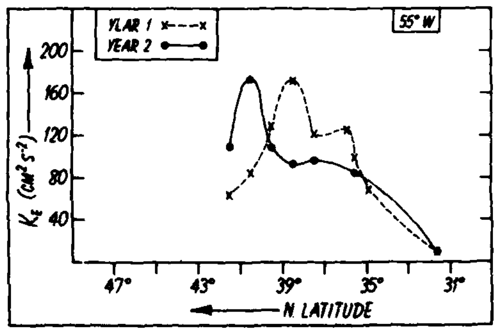

Fig. 5. Yearly averaged eddy kinetic energy K_E at 4000 m along 55°W in the North Atlantic.

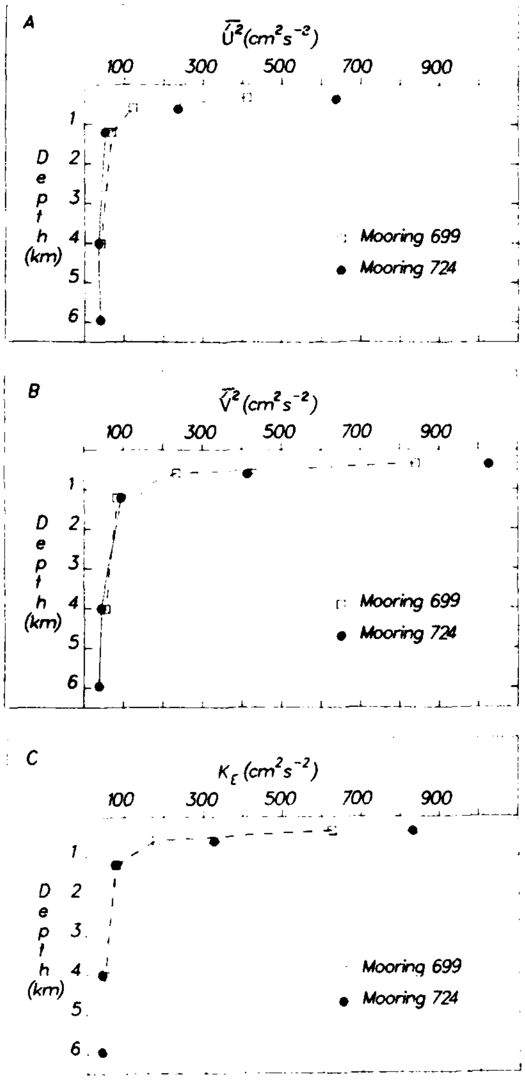

Fig. 6. A comparison of the vertical structure of the eddy field at moorings 699 and 724, both located in the vicinity of the Kuroshio Extension near 35°N (site WP05) at the center of the array: (*a*) $\overline{u'^2}$, (*b*) $\overline{v'^2}$, and (*c*) K_E.

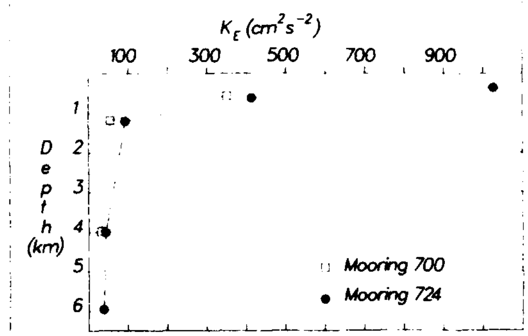

Fig. 7. Vertical distributions of eddy kinetic energy for moorings 700 and 724.

Site WP05 (moorings 699 and 724) is at the energetic center of the array within the Kuroshio Extension. The vertical structure of the eddy field at site WP05 changes quantitatively somewhat between mooring deployments, particularly at the upper levels, but not in general qualitative shape (Figure 6). Given the latitudinal shift of the K_E distribution in Figure 3 and the mean flow distributions (meandering) in Figure 4, it is also natural to intercompare, say, the vertical distribution of K_E relative to the axis of the Kuroshio Extension (Figure 7) between moorings 700 and 724 (a shift by one site for the most energetic moorings for each deployment). The quantitative correspondence near 600 m in Figure 7 is better than for Figure 6c, but qualitatively, the vertical profiles of K_E for moorings 699, 724, and 700 are all similar. The situation for $\bar{u}$ is much different, however: it is clear from Figure 8 that 698 and 724 are samples from a similar mean flow regime, but 699 and 700 are from other regimes. Moorings 698 and 724 have been compared by *Schmitz* [1984*b*, Figures 4 and 5], who shows that 698 is less energetic than 724 and has noticeably different spectral shapes (see below).

4. Frequency Distributions

The largest and only significant difference in K_E between settings in Figure 6 occurs for the mesoscale frequency range (Figure 9*a*) at 300 m (nominal). As a result, the upper level frequency distribution of K_E for 6991 is not peaked at the mesoscale as is the case for 7241. Note, however, that the percentage frequency distributions in Figure 9*b* minimize the visual impact of this observation. A similar situation occurs for 4000-m depth (Figure 10*a*), but in the opposite direction (i.e., 6994 is more peaked at the mesoscale than 7244), see also the percentage distributions in Figure 10*b*. The K_E vertical structure plots for moorings 699 and 724, although quantitatively rather different, are still qualitatively similar for each frequency band (Figure 11). In analogy to the case for the vertical structure K_E intercomparison in Figure 7, the frequency distributions for K_E are considerably more similar for moorings 700 versus 724 than for 699 versus 724 (Figures 12 to 14). As a consequence, the equivalent to Figure 11 for mooring 700 versus 724 shows quantitative agreement. The overall conclusion from Figures 6 through 14 is that 700 and 724, at positions shifted contrary to the direction of meandering of the Kuroshio Extension, are more quantitatively similar than any other intercomparison involving eddy energy characteristics near the energetic center of the array.

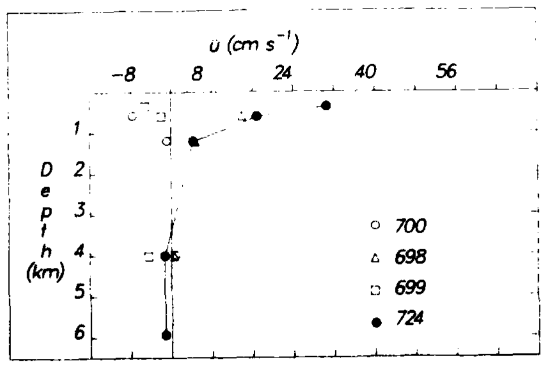

Fig. 8. The vertical structure of $\bar{u}$ for moorings 698, 699, and 724.

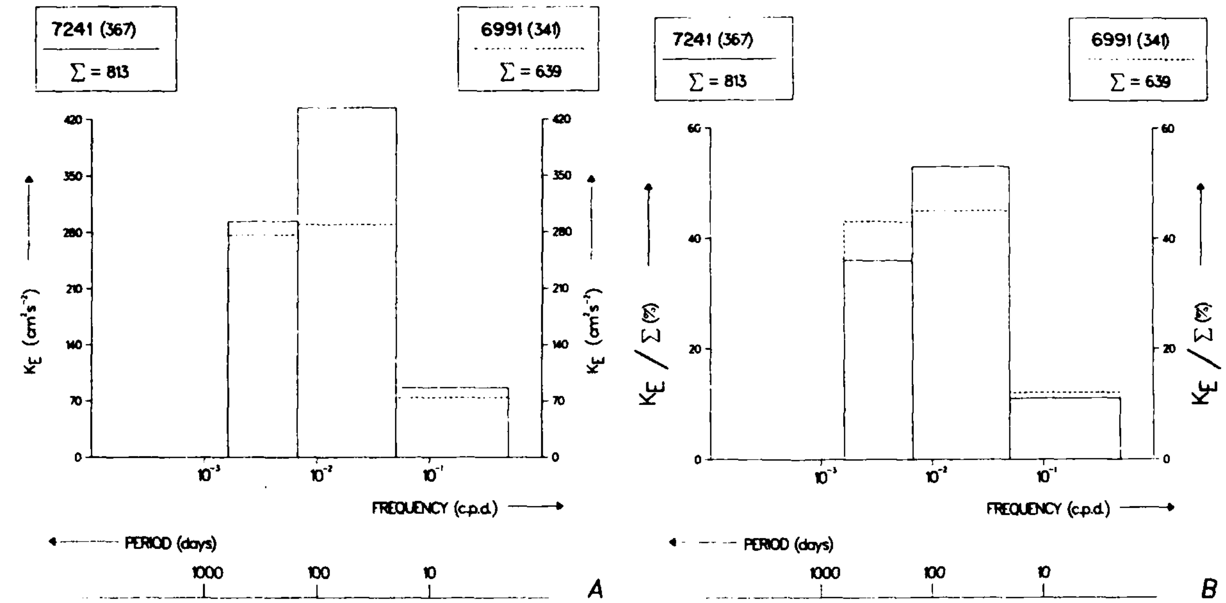

Fig. 9. Frequency distributions of K_E near 350-m depth for site WP05 (moorings 699 and 724).

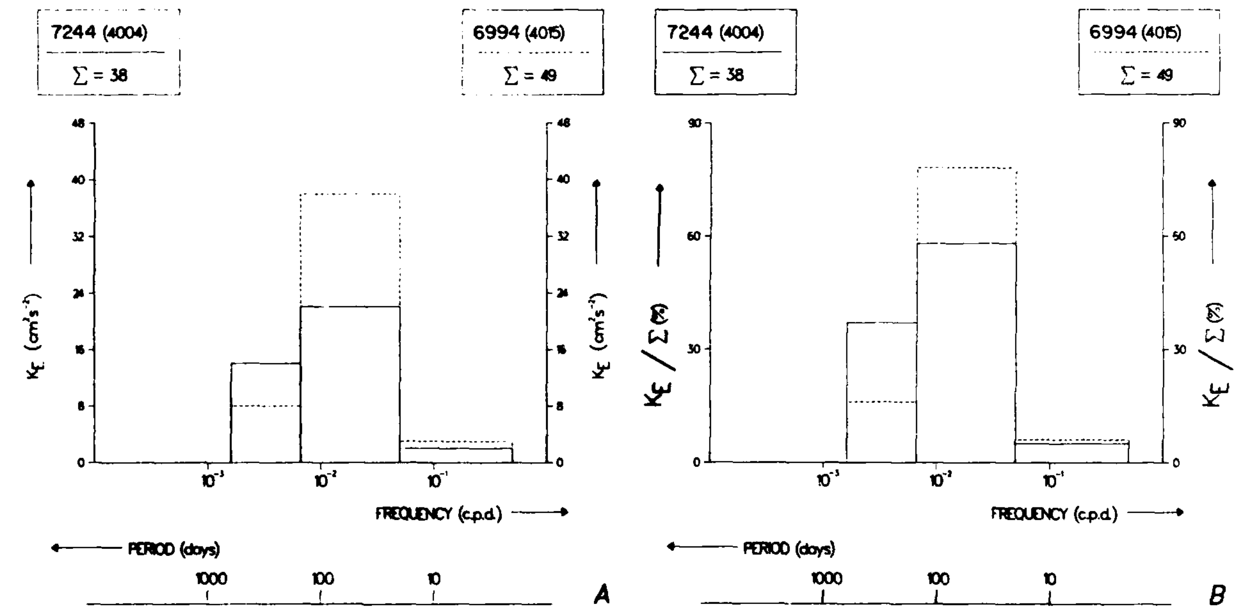

Fig. 10. Frequency distributions of K_E near 4000-m depth for moorings 699 and 724.

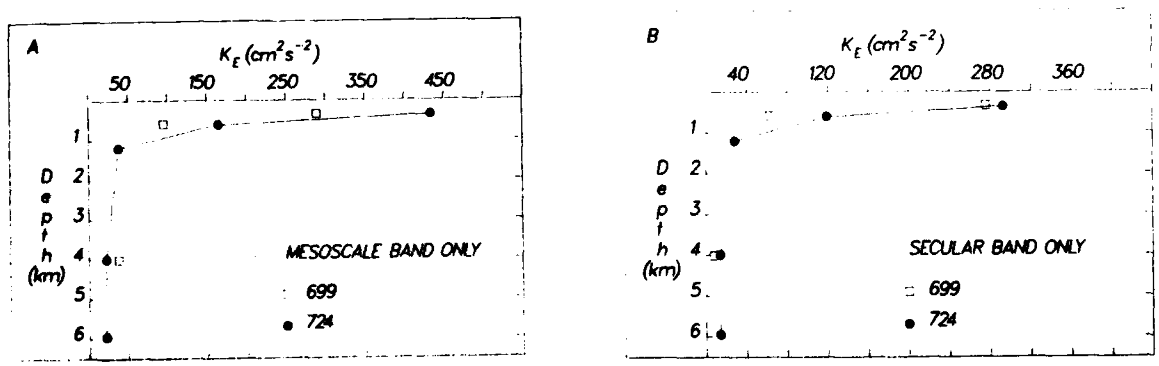

Fig. 11. Vertical distributions for K_E for different frequency bands for site WP05.

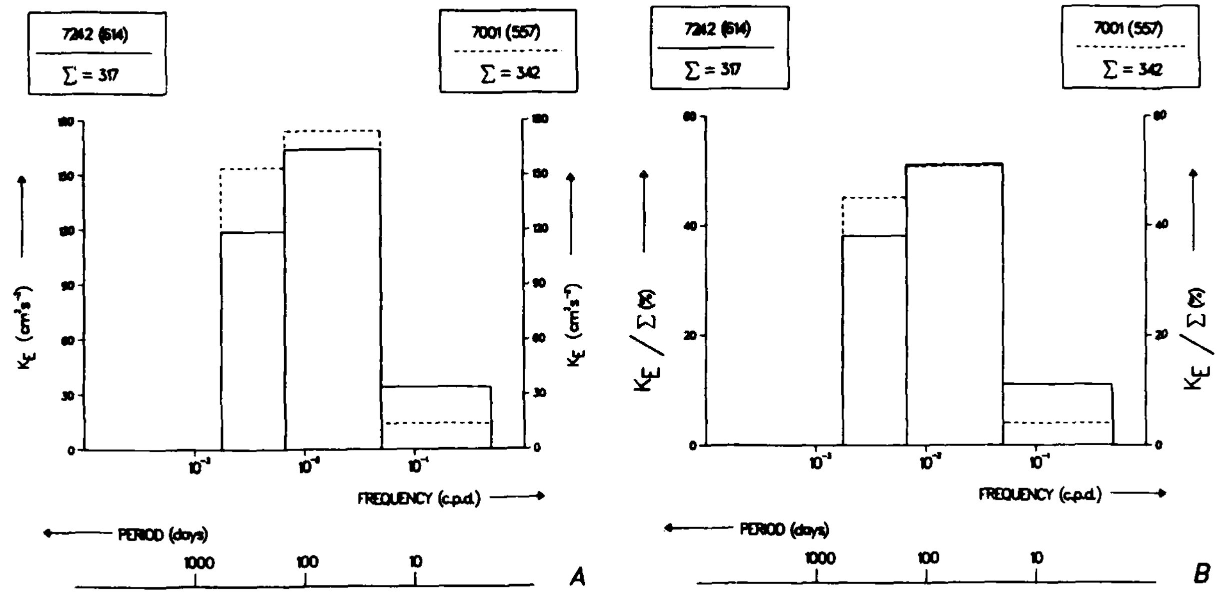

Fig. 12. Frequency distributions of K_E near 600-m depth for moorings 700 and 724.

The spectral variations associated with the prominent difference in $\overline{u'^2}$ at 4000 m near the north end of the array are summarized in Figures 15 and 16 to the extent possible (limited by the missing record at 39°N for the second array setting). Although the zonal kinetic energy (K_U) for 6954 is a factor of 3 higher than that at 7284 (Figure 15*a*), spectral shapes are similar (Figure 15*b*). However, there is a strong change in both spectral shape and amplitude at site WP03 (Figure 16).

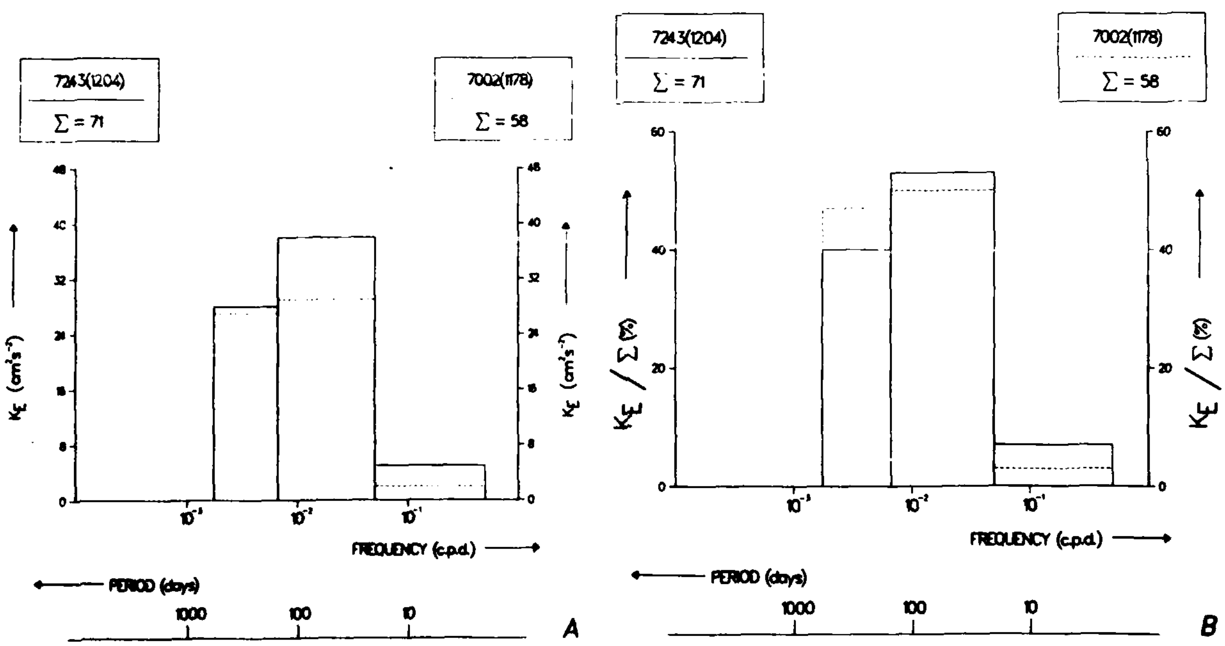

Fig. 13. Frequency distributions of K_E near 1200-m depth for moorings 700 and 724.

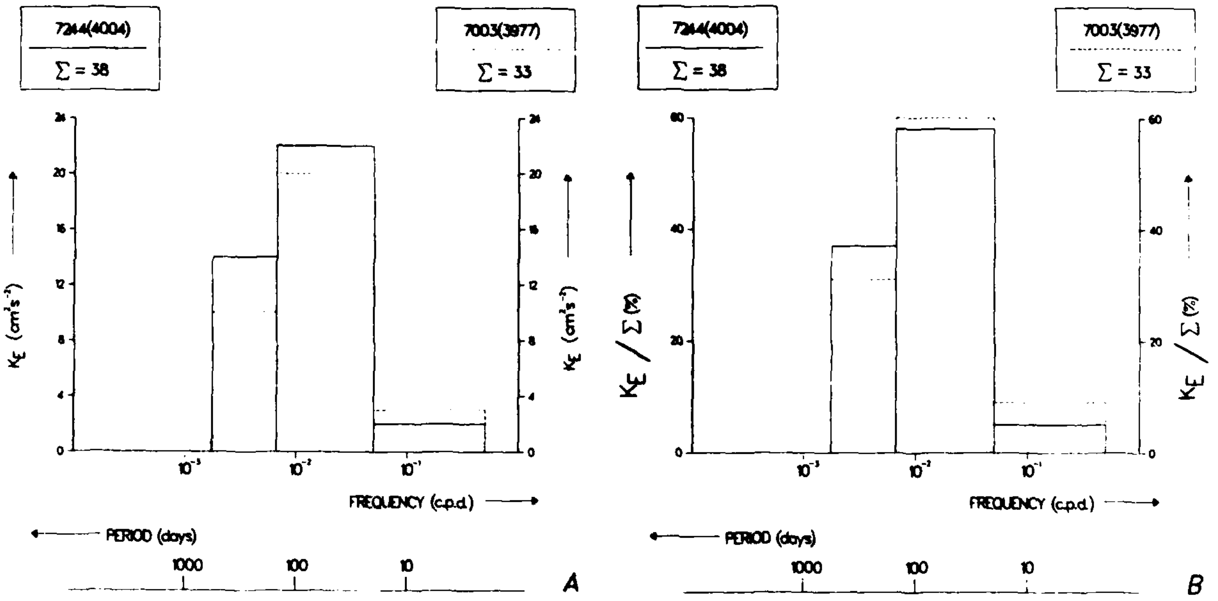

Fig. 14. Frequency distributions of K_E near 4000-m depth for moorings 700 and 724.

5. CONCLUSIONS

The first long-term moored array across a sizable section of the mid-latitude North Pacific [*Schmitz et al.*, 1982] was initially set in 1980 and recovered for the last time in 1982. Observations were made along 152°E from 28° to 41°N across the Kuroshio Extension, in two deployments of 10 moorings with 38 current-temperature meters for roughly a year each. Generally speaking, the deployment to deployment or year to

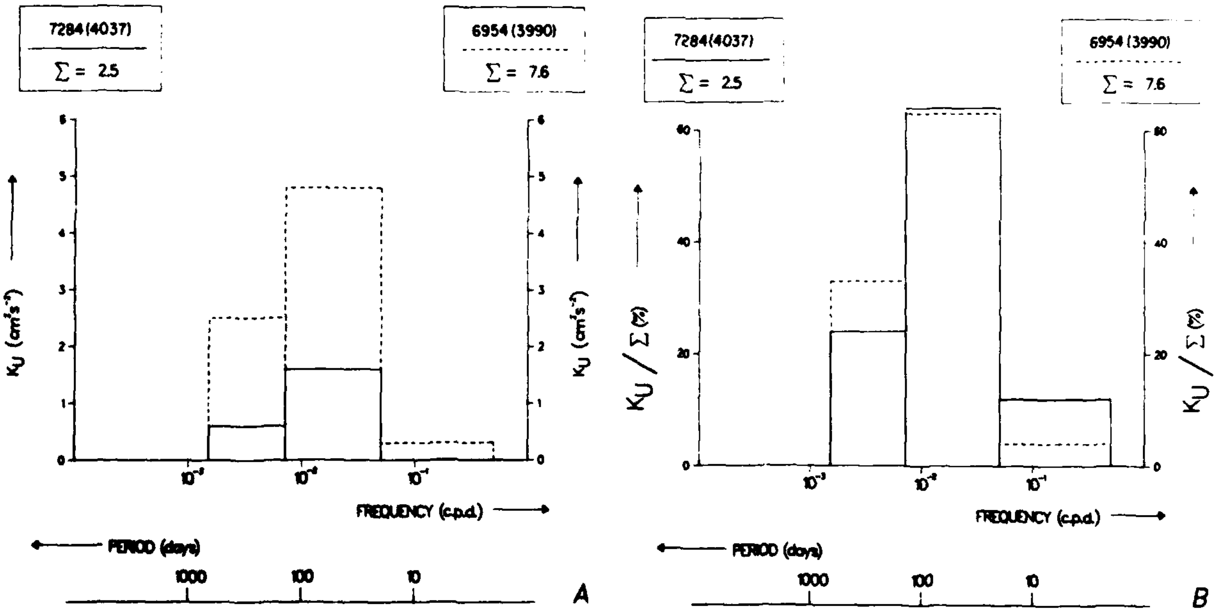

Fig. 15. Frequency distributions of K_E near 4000-m depth for site WP01 (moorings 695 and 728).

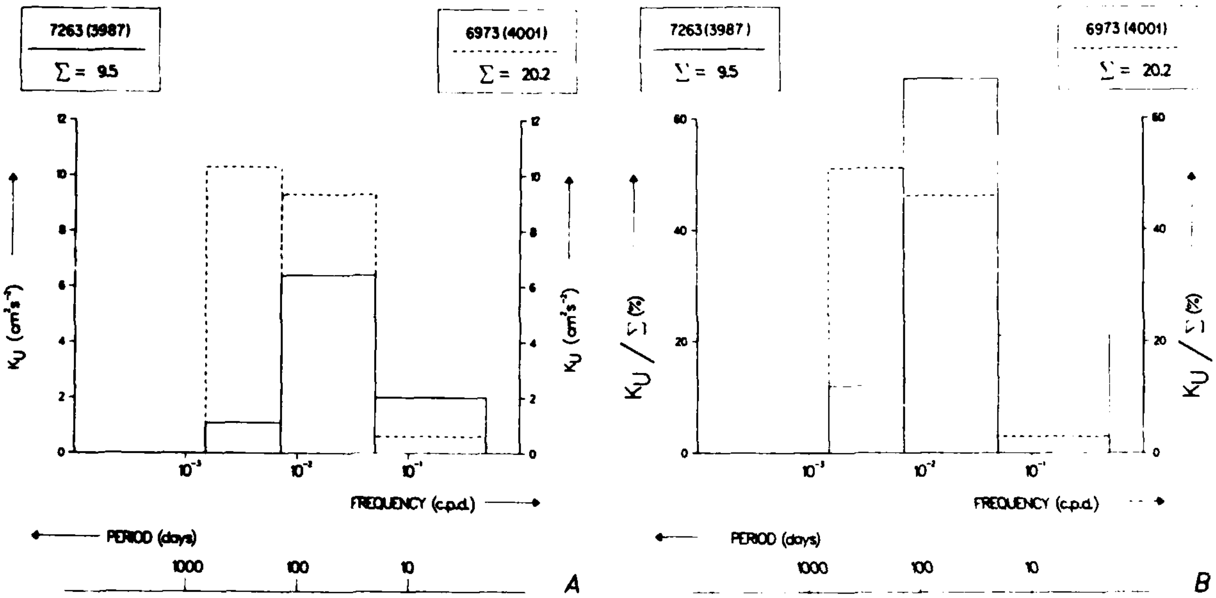

Fig. 16. Frequency distributions of K_E near 4000-m depth for site WP03 (moorings 697 and 726).

year (nominal) differences observed for various time averages were not large (with a few exceptions) relative to the axis of the Kuroshio Extension.

As was expected, eddy field characteristics are more stable than the mean flow, although not universally. However, the eddy energy patterns (and their frequency distributions) shift latitudinally in the opposite direction to meandering of the mean flow, whereas $\overline{u'v'}$ distributions translate in the same direction. There are notable year to year changes at 4000-m depth in both zonal mean flow and zonal eddy energy.

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